"Process for monitoring an aereal or spatial distribution"

This invention relates to a process with which the distribution of structures on a surface or of particles in space may automatically be monitored. In the event of deviations from the required state, warnings may automatically be output locally or remotely and/or corrective action initiated. The process is, for example, suitable for automatically monitoring the success of cleaning, chemical conversion and/or coating of surfaces, such as metal or plastic surfaces without requiring human intervention. One area of application is, for example, monitoring surface conversion or coating operations in the steel industry and automotive construction. The process is, moreover, suitable, for example, for monitoring the spatial distribution of particles in a spray jet. In such a case, it is possible automatically to monitor, on the one hand, the angle of divergence of the spray jet and, on the other, the homogeneity of the particle distribution in the spray jet. Applications for this latter case are, on the one hand, spray drying or spray solidification of solutions, suspensions or melts with the aim of maintaining the space/time yield of such processes at optimum levels. If, however, the purpose of spray jet is to coat a surface as uniformly as possible, the purpose of the process may be to maintain the coating process within the required range.

It is known in the art to store images of a surface in digitised form on a data storage medium and to subject them to automatic image analysis from various viewpoints. US-A-4 878 114, for example, describes a processor-based optical system for assessing the roughness of a planar surface of a product. This system comprises an adjustable light source to illuminate the surface, a video camera and a device for storing the video output signal in digitised form and a processor for analysing these digitised signals in such a manner as to determine a parameter which reproduces the roughness of the surface. The result of the image analysis is a single figure which characterises the roughness of the analysed portion of the surface. This result of the analysis contains no indication as to the existence and location of any particularly large deviations from the average roughness on the surface investigated.

EP-B-255 177 discloses a process for the automatic detection of a contrasting object in a video image stored in digitised form. To this end, threshold values above the background values are defined, above which an image element is considered to belong to a contrasting object. The process is accordingly directed towards detecting a pattern in a video image. It is not suitable for analysing the occurrence and spatial distribution of disturbances in an otherwise largely uniform video image if these disturbances do not describe a coherent object.

EP-B-428 751 provides a measurement method for assessing the quality of paper. In this method, variations in the light transmission of paper are assessed. The method involves a process for measuring textures which comprises recording an image of the transmitted light from a light source onto an area of paper using a camera in order to display the image of the transmitted light on a display unit of an image processing computer, dividing the image of the transmitted light on the display unit into a predetermined size and number of windows, which process is characterised by the calculation of an average intensity and a primary variance of the intensity of each window from the intensity of each of the pixels in each window, calculation of an average of the primary variance for all windows and a secondary variance from this first variance for all windows and the use of the secondary variance for all windows as a texture factor. This process thus yields a single index which describes the uniformity of the transmitted light and thus the homogeneity of the paper structure. This process does not detect individual faults and the position thereof on the paper surface.

EP-B-159 880 relates to a device for assessing the density and uniformity of a pattern, such as letters, printed on an article. The device is characterised by a means for calculating the density distribution of a plurality of image data in each of a plurality of segments of the pattern by sensing the density of each pixel of the image data; a means for checking the density distribution within each segment and, in those segments in which the density distribution satisfies a specified function, for standardising the density distribution in each such segment by dividing each density distribution value by a value which represents the overall density in the stated

segment; and a means for quantifying the density and uniformity of the patterns on the basis of the density distributions, which are standardised by the determining and standardising means, in which uniformity is defined as the degree of change of a standardised density within the pattern. This process is not directed towards identifying the occurrence and location of local disturbances in the pattern.

There are numerous industrial processes in which the quality of the result is characterised in that, after this industrial process, the appearance of a surface is as uniform as possible or in which a volume of space is as uniformly as possible filled with particles. One example of such a process is cleaning and/or hydrophilisation of metal or plastic surfaces. As a result of this processing stage, the surfaces should be covered as uniformly as possible by a film of water. Droplet formation, which is manifested in an image of a surface as a disturbance in uniformity, indicates a deficient cleaning or hydrophilisation result.

The aim of another group of industrial processes, such as phosphating, is to bring about a chemical conversion of a metal surface in order, for example, to protect this surface from corrosion. Disturbances in these processes are manifested as faults in the otherwise uniform surface coating. In an image of the surface, these faults are revealed by a deviation of the brightness thereof from the average brightness of the surface. A similar situation applies when coating surfaces with corrosion-protection coatings, such as lacquers. Disturbances in the uniform lacquer layer, such as blisters or craters, are also revealed as points having a brightness value which deviates greatly from the average brightness of the surface.

In other industrial processes in which liquid or solid particles are sprayed through one or more nozzles into space, it is important to determine the angle of divergence of the spray jet at the nozzle and the uniform spatial distribution of the particles in the spray jet. Clogging of the individual nozzles of a nozzle head is, for example, revealed by the space in front of the individual clogged nozzle being less densely filled with particles than the space in front of correctly operating nozzles. If the purpose of the spraying is to obtain a product by spray drying or spray solidification, clogged

nozzles result in a reduced space/time yield. If, however, the purpose of the spraying is to apply the particles as uniformly as possible onto a surface, clogged nozzles give rise to a non-uniform surface coating. When surfaces are coated by spraying liquid or solid particles, it may be of significance to the economic viability and the result of the coating process that the spray jet has a certain angle of divergence.

The uniformity of a surface in surface treatment processes or the uniform distribution of particles in a spray jet or the angle of divergence thereof are generally assessed by a visual assessment of the surface or spray jet either directly or from photographs. Human intervention is required for this purpose. Moreover, visual assessment may only be performed at certain intervals in time unless labour resources are to be occupied by devoting personnel exclusively to monitoring continuously the production result. If, as is generally usual, monitoring is performed only at certain intervals in time, there is a risk that defective products will have been produced between two periods of monitoring.

An object of the present invention is to provide automatic, continuous monitoring of processing or production processes, in which the quality of the result is manifested either as a uniform appearance of a surface or as uniform filling of a space with particles, and, in the event of disturbances, to output warnings and/or to analyse the causes of the disturbances and, where possible, to eliminate them.

The present invention accordingly provides a process for monitoring the distribution of structures on a surface or of particles in space, characterised in that:

(a) at least one two-dimensional image of the distribution is produced optically or electronically, is broken down into pixels and the brightness value of each pixel is stored in digitised form on a data storage medium;

(b) the image or a portion thereof is divided into a preselected number of image elements arranged in rows, wherein each image element comprises at least four pixels;

(c) the average brightness value of each image element is determined by averaging the brightness values of the individual pixels of this image element;

(d) the difference between the average brightness values of adjacent image elements is determined along a first specified row of image elements and recorded machine-readably on a data storage medium and/or output as a diagram in such a manner that a spatial correlation is obtained between the difference values and the position of the associated image elements on the image;

and, if desired,

(e) stage (d) is repeated with a preselected number of additional rows of image elements which are substantially parallel to the first specified row.

The phrase "at least one two-dimensional image" in sub-stage (a) here means that one image or two or more images of the distribution is/are recorded. One image is generally sufficient for assessing a substantially flat surface. When assessing a spatial distribution or a strongly curved surface, however, it may be advantageous to record two or more images, the image planes of which form a specified angle relative to each other. In this manner, the surface or spatial distribution may be assessed from various viewing directions. A video camera is preferably used to produce the image. The image portion may here be adjusted by the focal length of the video camera and/or by the distance of the camera from the article to be assessed. If very small portions of an article are to be assessed, such as may, for example, be necessary for monitoring the conversion of metal surfaces, the video camera may be provided with a microscope attachment. This process obviously presupposes that the surface to be imaged or the spatial zone to be recorded is sufficiently well illuminated. It is, for example, possible to use an apparatus as described in US-A-4 878 114 for recording and storing the image data in digitised form.

In sub-stage (b), the image or a preselected portion thereof is broken down into a likewise preselected number of image elements arranged in rows. The maximum number of image elements is here determined by the resolution of the camera used. The term pixel is hereinafter used to denote the smallest possible portion of the image, determined by the resolution, to which a brightness value (grey-scale value) may be assigned. The number of image elements into which the image may be broken down accordingly corresponds at most to the number of pixels assigned thereto. In

the process according to the present invention, however, image elements are advantageously selected which comprise two or more pixels. The average brightness value (grey-scale value) of each image element is determined by adding together the brightness values of the individual pixels and dividing the sum of the brightness values by the number of pixels. Computationally combining two or more pixels into a single image element in this manner reduces background noise by averaging. The image element is advantageously of such a size that it comprises at least four pixels, which are preferably arranged in adjacent pairs. However, depending upon the problem, an image element may also comprise substantially more pixels.

In order to obtain a meaningful result in the subsequent sub-stage (d), it is necessary for each row of image elements to contain at least two of these image elements. Advantageously, however, the selected number of image elements per row is substantially larger, for example in the range from about 10 to about 200 image elements, in particular about 15 to about 100 image elements per row. It is, in principle, sufficient for the performance of the process according to the present invention to work with a single row of image elements. More reliable results are, however, obtained if the image or portion of image is broken down into two or more rows, as it is possible in this manner to include a larger portion of the surface or of the spatial zone in the analysis. The image or portion of image is advantageously broken down into the same number of rows of image elements as each row has image elements. This means that an image or portion of image is broken down into about 10 to about 200, in particular into about 15 to about 100 rows.

The larger are the selected image elements, *i.e.* the more pixels they comprise, the better is the background noise eliminated by averaging. One should, however, avoid selecting image elements which are larger than the size of the expected defects. If the image is larger than a defect, there is a risk that the defect will not be detected. The portion of surface or space recorded as the image correlates with the number and size of the image elements. In general, it is advantageous to image an area or portion of space having a side length of between about 1 mm and about 5 m. The particular image portion may be set by establishing an appropriate distance between the camera

and object, by the focal length of the lens and optionally by using a microscope attachment. If, for example, the process is used to assess the result of a chemical surface treatment, it may be advisable to record and image a portion of surface of the order of 10 × 10 cm. When assessing a lacquer coating on a surface or the uniformity of a spray jet, image portions of the order of 30 × 30 cm may be particularly favourable.

In sub-stage (c), the average brightness value (grey-scale value) of each image element is determined by adding together the brightness values of the individual pixels of the image element and dividing the resultant sum by the number of pixels. Background noise is consequently reduced. Should this be insufficient, computational filter processes, such as a Gaussian or Fourier filter, may be applied before or after averaging. Gaussian filtering is, for example, also performed in the above-mentioned EP-B-255 177. However, for the purposes of the present invention, such filtering processes are necessary only in exceptional cases.

It is in sub-stage (d) that the actual criterion for assessing uniformity or detecting irregularities is produced. As is explained below, the angle of divergence of a spray jet may also be determined from the results of sub-stage (d). It is essential to the present invention in this connection to record or output the differences between the brightness values of adjacent image elements in such a manner that it is possible to detect which point on the imaged surface or in the imaged portion of space corresponds to a particularly large difference between the brightness values of adjacent image elements. Disturbances in uniformity are manifested by particularly large differences in the brightness of adjacent image elements. If the disturbances are "punctual", such as blisters or craters in a lacquer layer or so-called fish-eyes (light, crater-shaped defects) in a crystalline phosphating layer, it is possible in this manner to detect the occurrence, the number and the spatial distribution of these disturbances. Linear or areal disturbances, such as uncoated or differently coated points on the surface, are identifiable by the edge of disturbed surface being revealed in each row of image elements as a particularly large difference in the brightness values of adjacent image elements. A line fault is detected by the points having particularly

large differences on the individual rows of the image elements forming a continuous line. An areal disturbance which is smaller than the selected image portion is detected by generally two particularly large differences in the brightness values of adjacent image elements being identified in each row of image elements, the differences denoting the beginning and end of the disturbed surface. In a diagrammatic, two-dimensional representation of the differences in brightness values of adjacent image elements, the particularly prominent difference values circumscribe the area of the disturbance. It is, of course, necessary for this purpose to specify the difference in brightness values of adjacent image elements which is still accepted as noise and the threshold value from which the difference is characterised as a disturbance.

The background brightness of the image, which depends, for example, on the intensity of illumination, plays no part in the process according to the present invention, as the absolute brightness disappears when determining the differences in brightness values of adjacent image elements. It is, however, in any case advantageous to ensure the most uniform possible illumination of the surface or portion of space which is to be imaged. It is, for example, possible to use one or more light sources for this purpose, the cone of light of which is as parallel as possible to the camera axis. This minimises the formation of shadows. In particular, two to four light sources are preferably used which are arranged around the camera used to record the image. Superimposition of the individual cones of light results in particularly uniform illumination of the surface or portion of space. However, if an advantageous arrangement of light sources in this manner is not possible, non-uniform illumination of the surface or portion of space to be imaged may be corrected computationally by a so-called "illumination correction". The procedure used in this case is that, before determining the differences between the average brightness values of adjacent image elements, a preselected correction value is subtracted either from the brightness values of each individual pixel before the average brightness value of the image elements is determined or from the average brightness values of the individual image elements, or a preselected correction value is added to these brightness values, wherein the correction values associated with the individual pixels or image elements describe an area of the image or portion of image. The correction

values or the area on which these values lie may be determined either from substantially all pixels or image elements or from a statistically meaningful selection thereof. These correction values or the area on which they lie may be determined, for example, using the method of the minimum quadratic deviation of the individual observed brightness values from a compensating plane, which then constitutes the area of the correction values. In this manner it is possible computationally to offset the effect that one part of the image systematically appears darker than another when obliquely illuminated.

In order not to use a linear portion of the recorded image for identifying disturbances, but instead to use a larger, areal portion, sub-stage (d) is repeated in sub-stage (e) with a preselected number of further rows of image elements characterised as above, which are substantially parallel to the first specified row. Parallelism of the rows is preferable if the image portion to be analysed is rectangular and in particular square. This will generally be preferred. However, if the viewing direction of the camera is not at least substantially perpendicular to the surface to be recorded or to the axis of the spray jet to be recorded, the recorded image will contain perspective distortion. In this case, it may be preferable to select an image portion for analysis and also the individual image elements which are not rectangular, but instead trapezoidal, such that each image element corresponds to the same area of the recorded article or portion of space. In such cases, the rows of image elements are not necessarily parallel, but may instead form a (small) angle relative to each other which reproduces the perspective distortion of the imaged portion of the surface or spray jet.

When the image is analysed along substantially parallel rows of image elements, a linear or areal disturbance having an edge happening to run approximately parallel to the selected rows of image elements would not be detected. In order to exclude this risk, it is proposed to analyse the image portion (*i.e.* to determine the differences in brightness values of adjacent image elements) at least also along one or preferably two or more rows of image elements which form an angle relative to the first preselected row of image elements preferably in the range from about 60 to about 120° and in particular of the order of about 90°. In this manner, particularly large

differences in brightness values between adjacent image elements are detected along different directions on the surface, so increasing the reliability of the assessment process.

The process according to the present invention may, for example, be used for monitoring the distribution of structures on a metal or plastic surface. A portion of the surface which is as flat as possible is preferably selected for this purpose, which is in turn recorded from a viewing direction which is as perpendicular as possible. As already explained above, the assessment of a curved surface or an oblique viewing direction may be adjusted in such a manner that the viewing perspective is already taken into account in the selection of the individual image elements. In these cases, the size of the individual image elements is thus preferably selected in such a manner that each image element represents a substantially identical area of the recorded object. It may furthermore be advantageous with a curved surface to use the illumination correction described above. In any case, it is advisable to arrange the viewing direction and/or illumination in such a manner that shadows are not thrown on the image portion to be assessed.

The process may, for example, be used to monitor a metal or plastic surface, in which the success of cleaning and/or hydrophilisation is monitored. Successful cleaning and/or hydrophilisation is detectable from the fact that, on leaving the treatment zone, the surface is covered with a uniform film of liquid. Inadequately cleaned and/or hydro-philised points are in contrast discernible from the fact that the water film breaks up and coalesces into droplets or pools of water. With appropriate illumination, these points may be detected on the recorded image of the surface by the brightness values thereof which differ from the uniform background. These points may be identified by determining the differences between the brightness values of adjacent image elements according to the present invention.

The surface to be monitored may furthermore be a metal or plastic surface which has been chemically treated (for example cleaning or "conversion treatment", which changes the chemical nature of the surface) or coated. For example, it may be a metal

surface which has been subjected to chemical treatment in the form of chromating, treatment with an acidic solution of simple and/or complex fluorides, treatment with a solution of transition metal compounds or film-forming or non-film-forming phosphating. Such treatment stages are well known for corrosion protection treatment (optionally before subsequent lacquer coating) of industrially important metal surfaces, such as surfaces of iron, steel, galvanised or alloy-galvanised steel or of aluminum and alloys thereof. Such processes are routinely used in the metal-producing industry, such as in the steel industry, or in the metal-processing industry, such as in automotive construction or in the domestic appliance industry to improve corrosion protection. One specific application for the process according to the present invention is in the assessment of the quality of film-forming phosphating in automotive construction. In this case, deficiencies in quality are manifested by disturbances in the uniformity of the phosphate layer. These disturbances may, on the one hand, be substantially punctual, such as so-called phosphating "fish-eyes". The disturbances may, however, be more extensive and consist, for example, of unphosphated or less densely phosphated points on the metal. A portion of the surface having a size of 10 × 10 cm is preferably selected for this specific application. This image is broken down into a sufficient number of image elements that the phosphating fish-eyes, which extend from about 0.5 to about 2 mm, are still detectable as an individual disturbance.

The process may furthermore be used for monitoring a metal or plastic surface which has been coated with crosslinkable organic substances. One typical such example is a lacquer coating, which may be applied, for example, as an electrocoated lacquer coating, as well as by dipping in a lacquer bath or by spraying with lacquer. After application, such lacquers are conventionally cured by heating, by exposure to infra-red radiation or also by photochemical means, wherein appropriately reactive molecules join together and consequently crosslink. Such lacquer layers may exhibit various disturbances. These may be, for example, somewhat punctual disturbances, such as blisters or craters in the lacquer layer or also dust or soil particle inclusions, which are manifested as a raised point in the lacquer layer. Since, when appropriately illuminated, such disturbances reflect light differently to the undisturbed lacquer layer

and are in this manner discernible in the image of the lacquer layer as points of different brightness, they may be detected using the process according to the present invention as prominent brightness difference values of adjacent image elements. The disturbances may, however, be rather more extensive and be discernible by the systematic distribution described above of prominent brightness difference values in the individual rows of image elements.

In is in principle sufficient for the process according to the present invention to record an image of the surface to be monitored after the operation to be monitored (cleaning, chemical treatment, coating) and to analyse this image. In the case of operations which make only a slight change to the surface (cleaning, conversion treatment with the formation of layers in the sub-micron range), the brightness distribution of the image may primarily be determined by the structure of the metal surface itself. This may be the case, for example, with hot dip galvanised steel, where the brightness distribution of the metal surface is strongly influenced by the crystalline structure of the zinc layer. In such cases, it may be advisable in order to improve the meaningfulness of the process according to the present invention to remove the background structure computationally before the actual image analysis. To this end, the image of the surface before the operation to be monitored is compared with the image of the same portion of surface after this operation. The method used is that, according to sub-stage (a), a first image of at least approximately the same point on the metal or plastic surface is produced before and a second image after the chemical treatment or coating, before or after performing sub-stages (b) and (c) for the second image, the two images are at least approximately superimposed computationally by searching for characteristic points on the metal or plastic surface which are detectable on both images, these characteristic points on the two images are at least approximately superimposed and the brightness values of the pixels or the average brightness values of the image elements in the first image are then subtracted from the brightness values of the corresponding pixels or image elements in the second image, before sub-stages (d) and, if desired, (e) are performed with the second image.

It is necessary for this purpose to superimpose the two images at least to such an

extent that corresponding image elements on the two images at least largely overlap. It is, however, not generally necessary for the two images to be so precisely superimposed that each pixel of one image lies directly over the corresponding pixel of the other image. Depending upon the size of the image elements, deviations of the order of fractions of a millimetre to two or more millimetres are tolerable. Characteristic points which may be used for the computational superimposition of the two images are, for example, corners or edges produced by bends or seams or also joins of a small area, such as spot welds.

Alternatively, the two images could be computationally superimposed by displacing one image relative to the other image until the squares of the differences in the brightness values of the image portions displaced one over the other became minimal. This approach, however, demands substantial computational resources and is thus less suitable for rapid quality control.

The process may, for example, be used for the quality control of cleaning processes, chemical conversion processes and coating processes. In such processes, it is, for example, possible to define the range of differences in brightness of adjacent image elements which is considered the normal range. A range of larger difference values may be defined as the control range. It is tolerable in this connection if the differences in brightness values of adjacent images per image are up to n times within this control range, wherein n is a number to be specified of >1. If more than n difference values lying within the control range are observed, or if at least one difference value exceeds the control range, one of the following actions may be initiated automatically:

(i) a warning may be output locally or remotely;

(ii) start of checking of at least one piece of the treatment or coating equipment with which the metal or plastic surface has come into contact before sub-stage (a);

(iii) shut-down of the plant performing the cleaning and/or hydrophilisation, chemical treatment or coating.

Of course, two measures (i) and (ii) or (i) and (iii) may be initiated simultaneously. The process according to the present invention furthermore preferably provides for continuous recording on a data storage medium of the number of the difference values between the brightness values of adjacent image elements which lie within the normal range, within the control range and outside the control range. Recording is preferably performed in such a manner that it remains possible to associate the difference values with the treated article on which they were observed. A machine-readable bar code may, for example, be used for this purpose. The treated article may here, for example, comprise a steel coil or a section thereof or, in the case of automotive construction, a certain vehicle. In this manner it is possible automatically to keep and archive the records which are required for quality control and quality assurance.

It may furthermore be provided that trends in the difference values between the brightness of adjacent image elements over the course of the process according to the present invention are detected. For example, it is possible to detect a gradual degradation in the quality of the treatment stage preceding the process according to the present invention (cleaning, conversion treatment, coating *etc.*) from an increase in the numbers of difference values outside the normal range from image to image, for example from vehicle body to vehicle body. If such behavior is observed, it is possible to provide that the control system for the process according to the present invention outputs a warning locally and/or remotely.

For the purposes of this disclosure, local output of a warning is intended to mean that this warning is output within the works in which the process according to the present invention is performed. A "remote" location in contrast is intended to mean a location outside the works in which the process according to the present invention is performed. By means of the output to a remote location, it is possible to check and monitor those treatment stages which are to be monitored with the assistance of the process according to the present invention from a location outside the associated production plant. This remote location may, for example, be on the premises of the manufacturer of the chemicals which are used for the surface treatment stages to be monitored. In this manner, the manufacturer of the treatment chemicals is kept

continuously informed as to whether the corresponding treatment stages are proceeding normally on the user's premises.

If the maximum admissible number of difference values within the control range for the differences in brightness values of adjacent image elements is exceeded or if differences are observed which lie outside the control range, the computer system (control system) which performs the process according to the present invention, may, in accordance with alternative (ii), arrange for checking of at least one item of treatment or coating equipment with which the metal or plastic surface has come into contact before sub-stage (a). This may also proceed automatically if the control system for the process according to the present invention observes that the number of difference values lying within the control range increases by a specified amount.

It is additionally possible to take account of whether a relatively large number of prominent difference values between the brightness values of adjacent image elements are mutually independent and probably represent numerous punctual faults or whether these prominent difference values lie in a line or circumscribe an area and consequently belong to a single, but extensive fault. Various measures may be provided depending upon the result of such an analysis. For example, a line fault could still be tolerable, but not several punctual defects.

If the process according to the present invention is used, for example, for the quality control of a film-forming phosphating process for metal surfaces, one measure (ii) which may be provided is to check specified parameters of the phosphating bath or treatment baths, such as cleaning or activating baths upstream thereof. Automatic analysis of parameters to be specified of the phosphating bath, the activating bath or cleaning baths may, for example, be begun. In the case of cleaning baths, one or more of the following parameters may, for example, be automatically analysed: alkalinity, surfactant content and/or grease loading of the cleaning bath. Analytical methods which proceed automatically, as are described, for example in German patent applications 198 02 725, 198 14 500 and 198 20 800, may be used for this purpose. Furthermore, it may in turn be provided in relation to these bath monitoring measures

that corrective action is automatically initiated in the event of an observed deviation of the bath parameters from the required values.

By combining the monitoring process according to the present invention with an analysis of the upstream treatment baths initiated by the control system in the event of observed deviations, which analysis may in turn optionally automatically result in corrective action relating to the composition of the treatment baths, it is possible automatically and continuously to ensure the success of the surface treatment without human intervention being required for this purpose. It is advisable in this connection to store the results of the monitoring process according to the present invention together with the analytical and corrective action initiated in the event of deviation for subsequent evaluation.

The most serious measure (iii) which may be provided is that the control system automatically shuts down the entire plant if the number of difference values between the brightness of adjacent image elements within and/or outside the control range exceeds a specified number. It is, of course, preferable for the system to output an appropriate report locally and/or at a remote location so that the plant's operating personnel may take manual action as rapidly as possible and the disturbance may be eliminated.

The process according to the present invention may furthermore be used for monitoring the distribution of particles in a spray jet, in which at least one image of a particle jet produced by spraying through one or more nozzles is monitored. The image is here conveniently recorded substantially perpendicularly relative to the spray axis in order to avoid considerable perspective distortion. As explained above, slight perspective distortion may be offset by dividing the image into image elements in such a manner that each image element comprises an equally large portion of the spray jet and/or of the space surrounding it.

Especially in the case of a fan type spray jet, it may be sufficient to record a single image of the spray jet which is recorded as perpendicularly as possible relative to the

plane of the fan. In the case of a conical spray jet, on the other hand, it may be preferable to record two or more images of the spray jet which are recorded from different viewing directions. This means that in this case sub-stages (a) to (e) of the process according to the present invention are repeated once or more with images, the image planes of which (and thus the plane normals thereof) form a specified angle relative to each other. In the case of a substantially conical spray jet, it may be sufficient to perform the process according to the present invention using two images, the image planes of which are substantially perpendicular to each other.

The jet may, for example, comprise a particle jet, the particles of which consist of droplets of a solution or suspension which are dried in the particle jet to yield solid particles, or the particles may comprise droplets of a melt which solidify in the particle jet to yield solid particles. The first case describes a typical spray drying process, in which a solution or a suspension of a useful material is sprayed into a vacuum and/or into a zone of elevated temperature, wherein the solvent or suspending agent vaporises. In this manner, the useful materials are obtained in powder form. Such processes are used in various industries. Use in the foodstuffs industry, where powders of food and other substances for consumption are produced in this manner, may be mentioned by way of example. Examples are milk and coffee powder. Such spray drying processes are furthermore conventional in the detergent industry in order to obtain detergent active ingredients in powder form.

The process according to the present invention permits monitoring of whether the spray apparatus is operating normally, whether the spatial distribution of the spray jet is falling outside the normal range due to wear on the nozzles or whether non-uniformities in the spray jet are occurring due to clogging of individual nozzles in a group of nozzles. It is also possible to monitor whether the spraying process is proceeding optimally or whether there is a risk of reduced throughput due to disturbances.

The particles of the spray jet may furthermore comprise droplets of a solution, suspension or melt which are sprayed onto a surface in order to form a coating on

this surface. Liquid lacquers or lacquer dispersions are one such example. The particles may, however, also comprise solid particles with which a surface is coated. One such example is a powder coating. In both cases, irregularities in the spray jet result in irregular coating of the surface and thus in deficient quality.

In a similar manner to the measures described above relating to the monitoring of surface treatment processes, it is also possible to provide during monitoring of the particle distribution in a spray jet for automatic output of warning locally or at a remote location if the difference in the brightness values of adjacent image elements within the particle jet exceeds a specified amount. It is explained in the following example of monitoring the angle of divergence of a spray jet how it is possible to determine whether image elements are within or outside the spray jet. Continuous and automatic monitoring of spray processes is consequently possible without human intervention being required.

In a further embodiment, the process may be used to monitor the angle of divergence of a particle jet which is obtained by spraying through one or more nozzles. This may, for example, be of significance for spray drying or spray solidification processes. In such processes, the jet must not fan out too little as drying or solidification otherwise proceeds unreliably and there is a risk that the particles will agglomerate. On the other hand, the spray jet must not fan out too far as it is important to prevent tacky or viscous droplets from coming into contact with the wall of the spraying tower and adhering thereto. While the angle of divergence of the spray jet is indeed in principle predetermined by the arrangement of the nozzles, it may change due to wear or fouling of the nozzles. The angle of divergence of the spray jet is furthermore dependent upon the correct setting of the spray pressure.

If a spray jet is used for coating surfaces, such as coating with lacquer or underbody sealant in motor vehicles, care must also be taken to ensure a correct spray jet angle. Only if the angle of divergence of the spray jet is correctly set, will the surface to be coated be coated sufficiently uniformly and with the correct film thickness.

The portion of the spray jet to be recorded for determining the spray jet angle is primarily dependent upon the width of the spray jet. Spray jets for the production of bulk products, such as detergents, by spray drying extend to a considerable size of the order of some metres, such that a corresponding portion must be recorded in order to determine the angle of divergence. An image portion having a side length of up to 5 m may be convenient for this purpose. In the case of spray jets used for coating surfaces with, for example, lacquer or underbody sealant, an image portion having a side length of the order of a few centimetres up to about 1 m is generally sufficient. For example, in the specific example of applying underbody sealant, an image portion of a side length of about 10 to about 50 cm, in particular of the order of about 30 $\times$ 30 cm, is suitable.

The process according to the present invention for monitoring spray jet angle is preferably performed by breaking the image down into lines which are perpendicular to the axis of the spray jet. An adequate number of image elements per line is selected (in the range from about 10 to about 200, preferably from about 15 to about 100 image elements per line) and the differences in brightness between adjacent image elements are determined starting from one edge of the image. Given suitable illumination, the differences in the brightness values of image elements which represent only the background are relatively small. The difference in brightness values of adjacent image elements, one of which predominantly contains the image of the background and the other predominantly contains the image of the spray jet will, however, be particularly large. The differences in brightness values of adjacent image elements solely containing spray jet will, on the other hand, again be relatively small (provided that the spray jet is not excessively non-homogeneous). The process of determining the differences will thus pass from the background into the spray jet, move across the spray jet and re-emerge into the background. The final large difference value between the brightnesses of adjacent image elements will then most probably correspond to the edge of the spray jet. As the process moves along a line, small differences in brightness values of adjacent image elements will first of all be detected, then a first large difference value on detection of one edge of the spray jet, slightly varying difference values within the spray jet and one further particularly

large difference value corresponding to the other edge of the spray jet. This process of course presupposes that the selected image portion is of such a size that, in addition to the image of the spray jet, it also includes an image of the background on both sides. This may be monitored automatically by requiring that the image give rise to the above-stated pattern of difference values.

The procedure applied here is preferably to begin determining the differences in brightness values of adjacent image elements in the image line closest to the spray head. Since the size of the spray head is known, it is most readily ensured that the central part of the image line will contain an image of the spray jet and an image of the background on each end. The analysis is then continued in lines progressively further away from the nozzle head and it is monitored whether extreme differences in the brightness values of adjacent image elements move outwards on each successive line. This will continue to be the case for as long as the image line comprises background at each end and spray jet in its central zone. This process is terminated once the extreme differences between the brightness values of adjacent image elements reach the margins of an image line, as there is then a risk that the image line will then contain only spray jet, but no longer any background. The required information is then no longer present in this image line.

The angle of divergence of the spray jet may be calculated from these observations by plotting a curve through at least two significant points, preferably a fitted curve passing through several points, denoting the first large difference values between the brightness of adjacent image elements in the individual image lines. A second curve or fitted curve is plotted in a similar manner through the points denoting the last large difference values in the brightness of adjacent image elements on the individual lines. The profile of the two curves on the image may be represented as a vector. The angle of divergence of the spray jet may be calculated from this vector using vectoral algebra.

However, in many cases, instead of determining the exact angle of divergence of the spray jet, it is sufficient to monitor whether the angle of divergence remains within

the required range over time. To this end, it is possible to specify to the evaluation unit for the process according to the present invention the range of the image within which the first and last large differences between the brightness values of adjacent image elements must lie on selected image lines. If the identified extreme values of the differences of the brightness values lie further inwards, the angle of divergence of the spray jet has reduced, while if they lie further outwards, the angle of divergence has increased.

If the evaluation unit for the process according to the present invention establishes, either by calculating the spray jet angle, for example by a vector calculation, or, in accordance with the last-stated method, by comparing the required positions of extreme difference values on the individual image lines with the actual position thereof, that the spray jet angle has moved outside a tolerance range, *i.e.* falls below or exceeds a specified angle range, one or more of the following actions may be initiated:

(i) output of a warning;

(ii) modification of the spray pressure in the direction which returns the angle of divergence of the spray jet to within the specified angle range;

(iii) modification of the viscosity of the composition from which the spray jet is produced in the direction which returns the angle of divergence of the spray jet to within the specified angle range;

(iv) modification of the electrical charge of the particles of the spray jet or of electric fields in the vicinity of the nozzles in the direction which returns the angle of divergence of the spray jet to within the specified angle range,

(v) shut-down of the spray jet.

The simplest measure is to output a warning locally or at a remote location. It may be provided in this connection that while a warning is indeed output in the event of a slight change in the angle of divergence of the spray jet, no further action is initiated. Only once a threshold deviation of the spray jet angle, to be specified, is

reached may one of actions (ii) to (iv) be automatically initiated. It may, of course, also be provided that the spraying process is completely suspended if the spray jet angle falls below or exceeds a limit value to be specified.

It may be specified to the control system whether the angle of divergence of the spray jet should be adjusted by modifying the spray pressure, by modifying the viscosity of the composition to be sprayed (for example by changing the temperature of the composition in the spray head) or by modifying the electrical charge. It may furthermore be specified to the control unit which modification of the spraying conditions should result in an increase or decrease in the spray jet angle. The control system may, however, also be designed such that it itself learns which measure most reliably returns the angle of divergence of the spray jet to within the required range. To this end, the control system may modify the possible spray parameters at will and, by analysing the image of the spray jet, analyse the consequence of this action on the angle of divergence of the spray jet.

It may furthermore be provided that, in the event that a modification of the spray parameters does not result in the desired success, the control system outputs an alarm (locally and/or to a remote location) and simultaneously proposes possible action. Possible proposed action may, for example, involve cleaning or replacement of nozzles. It is preferably also provided that the control system shuts down the spraying process in such cases.

This process for monitoring the angle of divergence of a spray jet may, for example, be used for the lacquer coating of surfaces and in particular for the application of underbody sealant onto vehicles. One obvious measure for correcting the angle of divergence of the spray jet in the case of the application of underbody sealant is in particular to vary the temperature of the underbody sealant composition to be applied, in the area of the spray head. The resultant modification of the viscosity of the underbody sealant composition has a particularly distinct effect on the angle of divergence of the spray jet, such that a correction may readily be made using this measure.

It is also preferably provided for this embodiment to store the results of monitoring the angle of divergence of the spray jet for subsequent evaluation and/or for quality control. This record preferably includes the correlation of the angle of divergence determined at a specific point in time with this point in time and/or with the article coated at this point in time.

Examples

Example 1:

Monitoring of the homogeneity of a zinc phosphate layer on a steel sheet

The upper half of Figure 1 shows the video image of a steel sheet phosphated by a film-forming zinc phosphating process. In the lower image, the phosphate layer has been deliberately damaged in order to simulate phosphating defects. The added grid represents in each case the division into individual image elements, for which the differences in average brightness values are to be determined according to the present invention.

The image portion is of a size of about 11 × 8 cm in each case.

Figure 2 shows the result of determining the differences of the average brightness values of adjacent image elements, in each case along a horizontal line on the figure. In this figure, the diagram of the upper half of the image corresponds to the undamaged phosphated sheet from Figure 1, while the diagram in the lower half of the figure corresponds to the damaged phosphate layer in the lower half of Figure 1. The differences in brightness values of adjacent image elements along horizontal lines in Figure 1 are reproduced as horizontal lines in Figure 2. The individual horizontal lines of image elements in Figure 1 correspond to the individual lines in Figure 2.

In the upper half of Figure 2, it is clear that, on a defect-free and uniformly phosphated sheet, only slight differences in the average brightness values of adjacent image elements occur. In comparison, the disturbances of the phosphate layer in the

lower half of Figure 1 result in greater differences in brightness values of adjacent image elements, as is evident in the lower half of Figure 2. Phosphating defects may thus automatically be detected by the differences in brightness values of adjacent image elements exceeding a specified minimum amount. The lower half of Figure 2 simultaneously shows that the extent and location of the phosphating defect may be detected.

Example 2:

Monitoring of the angle of divergence of a spray jet for the application of underbody sealant

The lower half of Figure 3 shows the video image of a spray jet for the application of underbody sealant onto an automotive body. The video image was optically filtered in order to make the boundaries of the spray jet and the non-uniformities thereof more clearly detectable. The grid reproduces the selected image elements, wherein the entire image portion is of a size of about 16 × 12 cm. The upper half of the figure shows the result of determining the differences in average brightness values of adjacent image elements in each case along a horizontal line. Successive lines in the upper half of the image correspond to the successive rows of image elements in the lower half of the figure. The outer delimitation of the spray jet and non-uniformities within the spray jet are detectable by particularly large differences in the brightness values of adjacent image elements.

It is consequently first of all possible to assess the homogeneity of the spray jet. It is furthermore possible to monitor whether the angle of divergence of the spray jet changes over time. To this end, video images recorded at different times are compared and it is checked whether the edge of the spray jet in each case falls within corresponding image elements on the individual recordings.

The spray jet angle may, however, be determined directly from the representation of the differences in brightness values of adjacent image elements according to the upper half of Figure 3. The following algorithm may be used for this purpose: if the above-

mentioned delimiting curves of the spray jets are represented by the following curve equations

$$y = a \cdot x + b \quad \text{and} \quad y = c \cdot x + d,$$

the angle of divergence, alpha, of the spray jet is obtained in accordance with the formula:

$$\cos \text{alpha} = \frac{-(1 + \cdot c)}{\text{sqrt}(1 + a \cdot a) \cdot \text{sqrt}(1 + c \cdot c)}$$

"sqrt" here denotes the square root function. The reference point and the orientation of the coordinate system used for the curve equations play no part in the determination of the angle of divergence and may be selected in accordance with practical considerations. Both delimiting curves must, however, be represented in the same coordinate system and identical distances on the x axis and y axis must correspond to identical lengths on the object (in this case in the spray jet). In general, the coordinate system will be selected such that, for example, the x axis is exactly horizontal and the y axis vertical on the recorded video image.

Figure 4 shows the application of this process to the spray jet according to Figure 3. The upper part of Figure 4 is a schematic representation of the points on the individual lines in Figure 3 (top) at which the outermost large differences in the brightness values of adjacent image elements are detected. These correspond to the delimiting line of the spray jet. The curve equation for each of the two delimiting lines of the spray jet is stated below and, from these, the angle of divergence of the spray jet is calculated by vectoral algebra. In this Example, the angle is 47°.

List of Figures

Figure 1

Video recordings of a portion of a steel sheet phosphated with a film-forming zinc phosphating solution.

Top: phosphate layer in original state

Bottom: phosphate layer subsequently damaged by scratching

Size of image portion in each case about 11 × 8 cm.

Figure 2

Graphical representation of the differences in brightness values of adjacent image elements in Figure 1. The upper and lower halves of the figure correspond in each case. Successive lines in Figure 2 correspond to successive rows of image elements in Figure 1.

Figure 3

Bottom: optically smoothed video image of a spray jet for applying underbody sealant. The size of the image portion is about 16 × 12 cm.

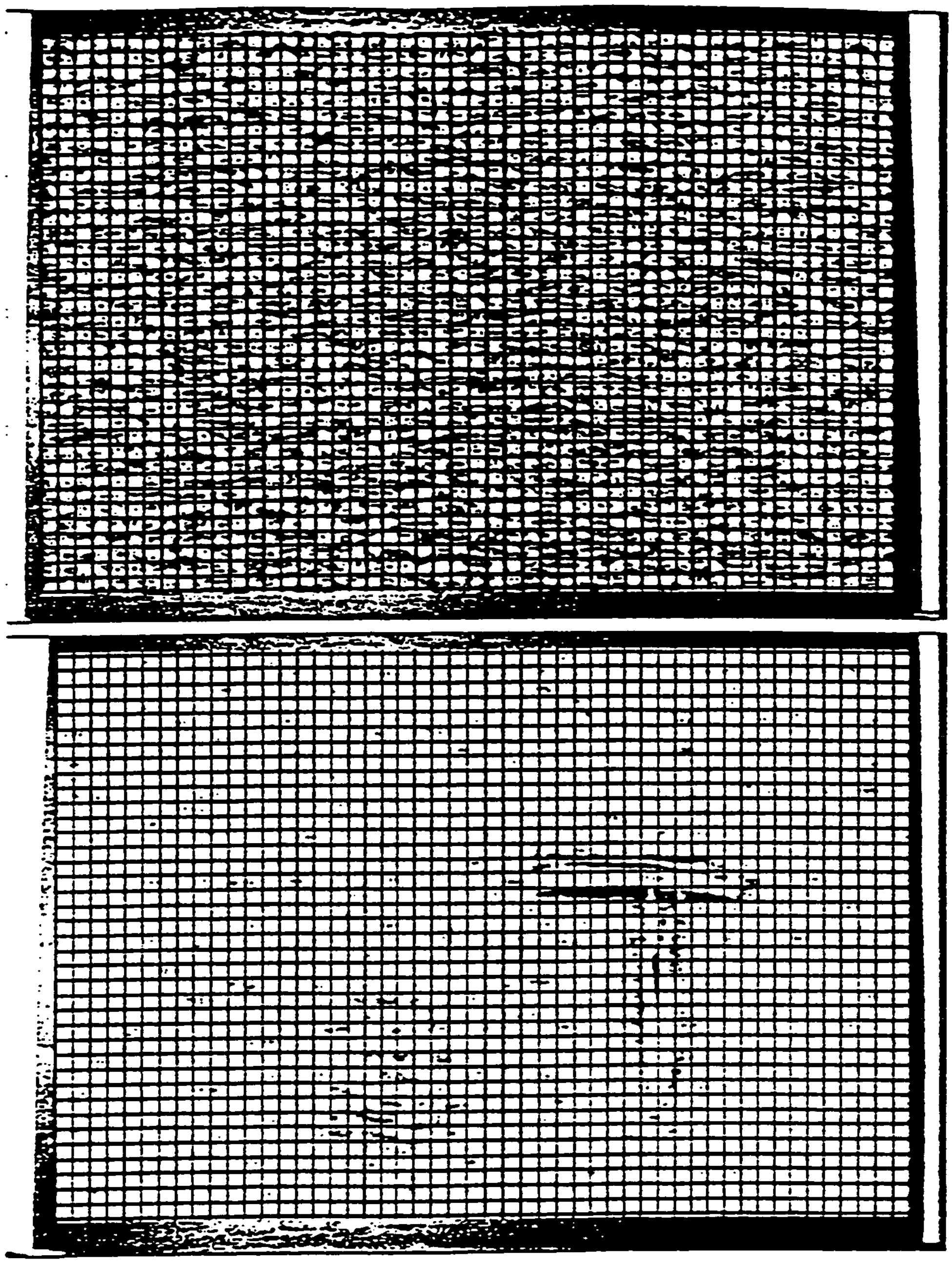
Top: Differences in brightness of adjacent image elements in the lower part of the figure plotted in lines. Successive lines correspond to successive rows of image elements.

Figure 4

Top: schematic position of the outer significant difference values of adjacent image elements in Figure 3, top, which indicate the delimitation of the spray jet.

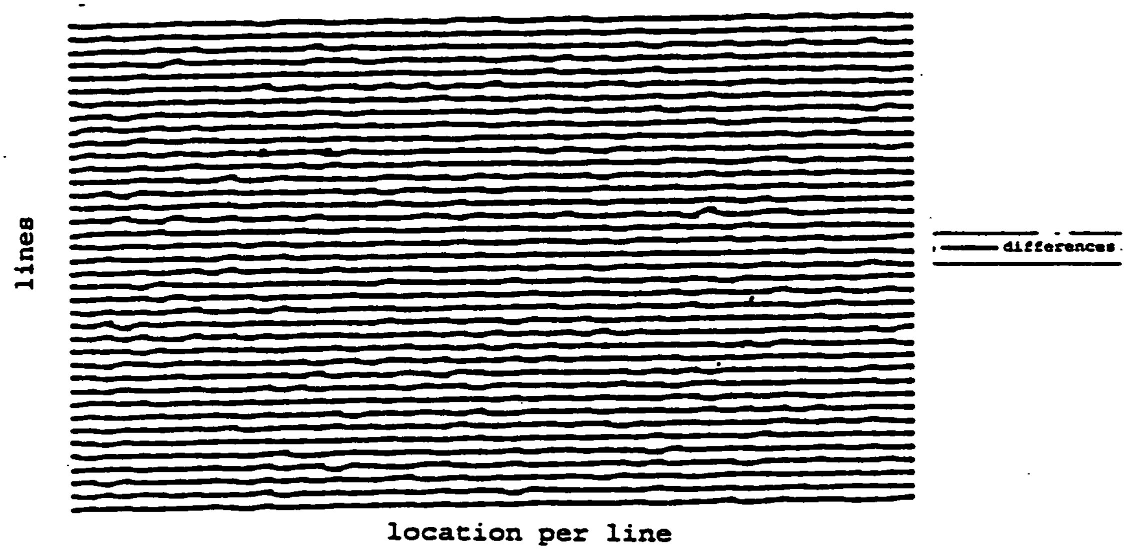
Bottom: calculation of the angle of divergence of the spray jet.

Figure 1



<u>Figure 2</u>

Homogeneity of the grey-scale values of a phosphated sheet



Homogeneity of the grey-scale values of a blemished phosphated sheet

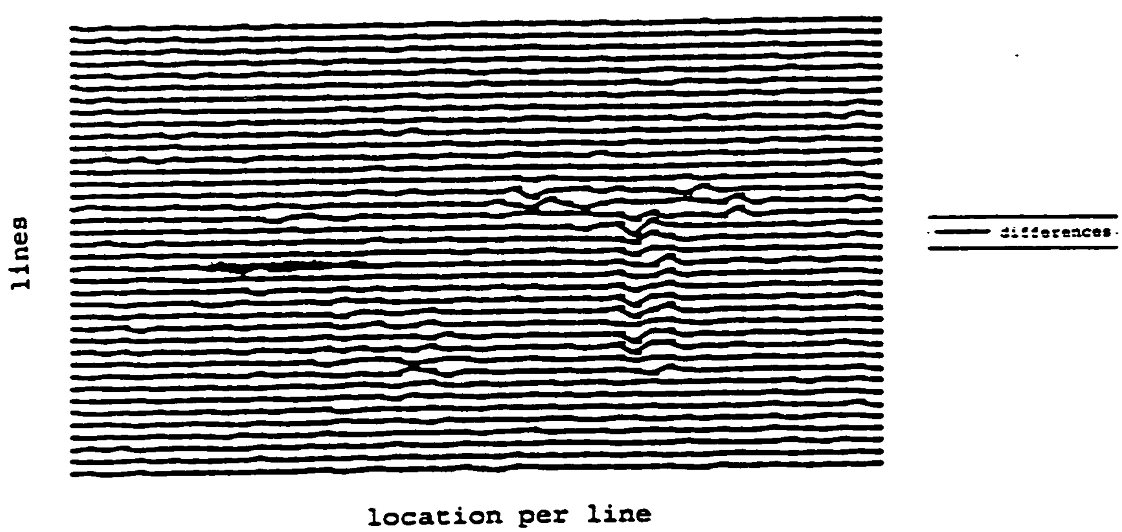
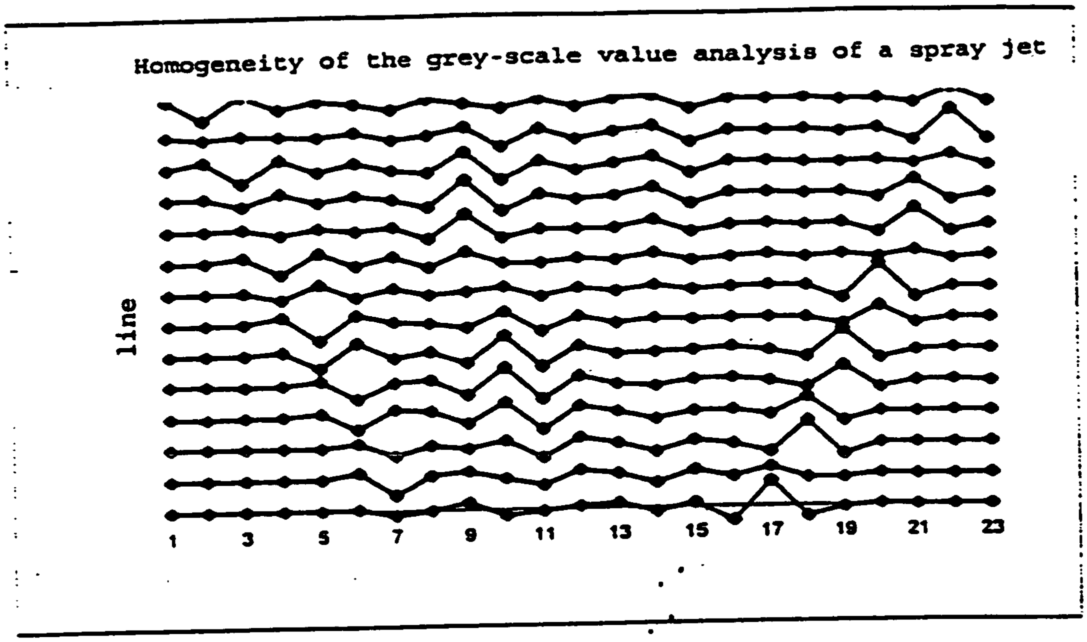


Figure 3


Homogeneity of the grey-scale value analysis of a spray jet
line
1
3
5
7
9
11
13
15
17
19
21
23

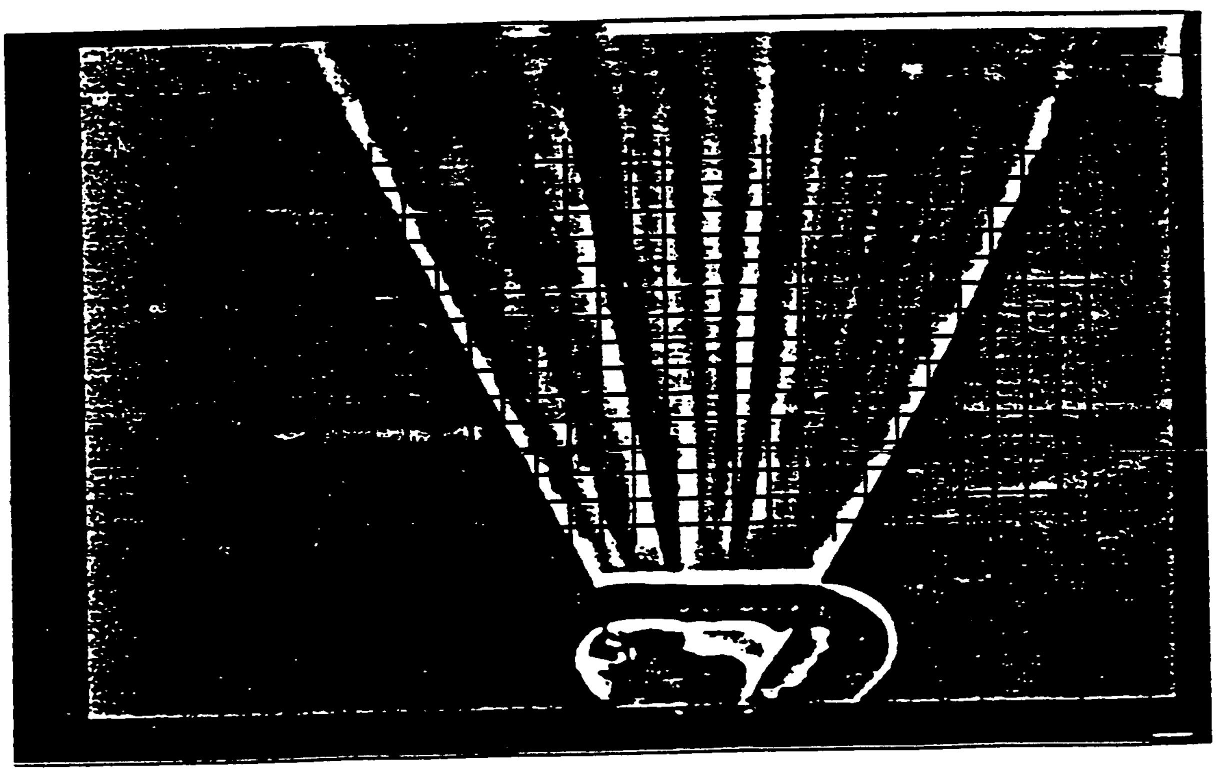
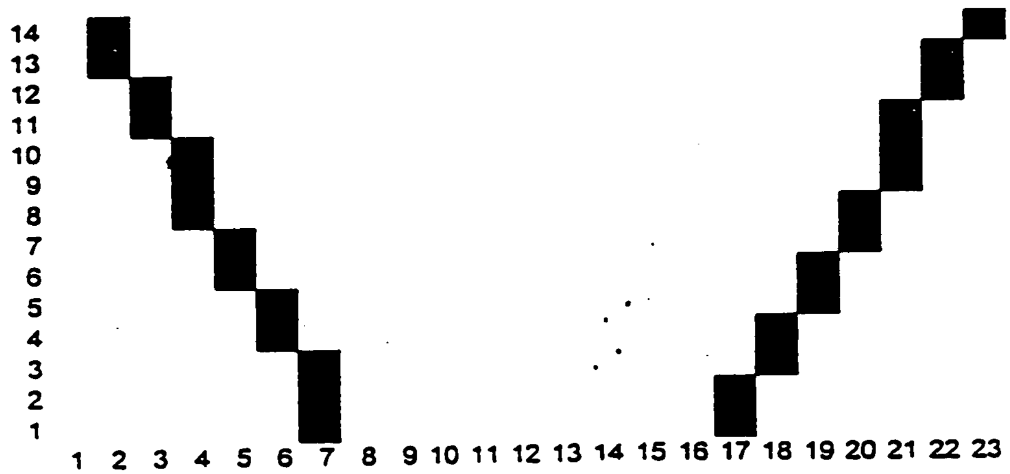


Figure 4



$y = a*x+b$ $\qquad\qquad$ $y=c*x+d$

$$\cos\alpha = \frac{-(1+a*c)}{\mathrm{sqrt}(1+a*a) * \mathrm{sqrt}(1+c*c)}$$

$y = 18.26 - 2.317 * x$ $\qquad\qquad$ $y = -37.58 + 2.278 * x$

$$\cos\alpha = \frac{+4.278126}{6.2782}$$

$\cos\alpha = 0.6814$

$\alpha = 47°$